

AD-A157 660

HIGH PRESSURE AND MOLECULAR WEIGHT VARIATION OF  
ELECTRICAL RELAXATION IN POLY(ETHYLENE OXIDE)(U) NAVAL  
ACADEMY ANNAPOLIS MD DEPT OF PHYSICS

1/1

UNCLASSIFIED

J J FONTANELLA ET AL. JUN 85 TR-15

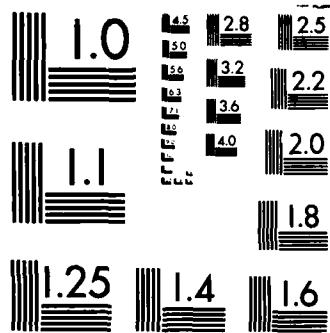
F/G 7/4

NL

END

FILMED

DTIC



MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

AD-A157 660

FILE COPY

2

OFFICE OF NAVAL RESEARCH

Contract N00014-85-AF-00001

Task No. NR 627-793

TECHNICAL REPORT NO. 15

HIGH PRESSURE AND MOLECULAR WEIGHT VARIATION OF ELECTRICAL RELAXATION IN  
POLY(ETHYLENE OXIDE)

by

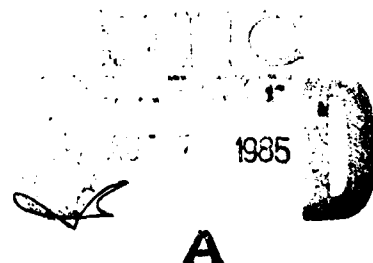
John J. Fontanella & Mary C. Wintersgill

Prepared for Publication

in

Journal of Applied Physics

U. S. Naval Academy  
Department of Physics  
Annapolis, MD 21402



June 1985

Reproduction in whole or in part is permitted for any purpose of the United  
States Government

This document has been approved for public release and sale; its  
distribution is unlimited

85 7 31 026

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 15	2. GOVT ACCESSION NO. <b>A157660</b>	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) HIGH PRESSURE AND MOLECULAR WEIGHT VARIATION OF ELECTRICAL RELAXATION IN POLY(ETHYLENE OXIDE)		5. TYPE OF REPORT & PERIOD COVERED Interim technical report
7. AUTHOR(s) JOHN J. FONTANELLA & MARY C. WINTERSGILL		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Physics Department U. S. Naval Academy Annapolis, MD 21402		8. CONTRACT OR GRANT NUMBER(s) N00014-85-AF-00001
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research Attn. Code 413, 800 N. Quincy St. Arlington, VA 22217		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR No. 627-793
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE June 1985
		13. NUMBER OF PAGES 23
		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release and sale. Distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Solid electrolytes, polymer electrolytes, poly(ethylene oxide), electrical relaxation, high pressures, molecular weight.		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Vacuum audio frequency complex admittance measurements have been performed on poly(ethylene oxide) using a fully automated dielectric spectrometer. Measurements have been made over the temperature range 5.5-320 K for molecular weights from $1.85 \times 10^4$ to $4 \times 10^6$ . The $\tau$ relaxation is essentially unchanged over the range of molecular weights studied. This represents evidence against assigning the $\tau$ relaxation to the motion of		

Revised 10/10/1994

A-1



High Pressure and Molecular Weight Variation of Electrical Relaxation in  
Poly(ethylene oxide)

Mary C. Wintersgill, John J. Fontanella, Peter J. Welcher

Physics Department

U.S. Naval Academy

Annapolis, Md. 21402

and

Carl G. Andeen

Physics Department

Case Western Reserve University

Cleveland, Ohio 44106

# ABSTRACT

Vacuum audio frequency complex admittance measurements have been performed on poly(ethylene oxide) using a fully automated dielectric spectrometer. Measurements have been made over the temperature range 5.5-320K for molecular weights from  $1.85 \times 10^4$  to  $4 \times 10^6$ . The  $\gamma$  relaxation is essentially unchanged over the range of molecular weights studied. This represents evidence against assigning the  $\gamma$  relaxation to the motion of end groups. Next, previously reported data for the  $\gamma$  relaxation is reanalyzed using a reduced plot. The activation volume is found to be 3-4  $\text{cm}^3/\text{mol}$  in good agreement with the previous work and the small value implies that the relaxation is associated with the motion of very small segments of the polymer chain. Next, the relaxation associated with the glass transition,  $\alpha_a$ , is only observed in temperature for some samples but is observed in both frequency and temperature for others. The strength of  $\alpha_a$  decreases monotonically as molecular weight decreases. Finally,  $\alpha_a$  was studied up to pressures of about 0.2 GPa for  $5 \times 10^6$  molecular weight material. The results for the shift of  $\alpha_a$  with pressure are in qualitative agreement with recent theories.

## I. INTRODUCTION

Poly(ethylene oxide) (PEO) is of current interest as the prototype polymeric solid electrolyte.<sup>1-3</sup> As a consequence, the basic properties of this material, and particularly the electrical properties, are being extensively studied. As a result, there is a considerable amount of literature relating to this material. Much of the early work has been reviewed by McCrum et al.<sup>4</sup> and Hedvig.<sup>5</sup> References to some of the more recent work can be found in the papers by Porter and Boyd,<sup>6</sup> and Se et al.<sup>7</sup> More recently, the authors have presented<sup>8-11</sup> the results of audio frequency electrical relaxation (DR) measurements on PEO and PEO complexed with a variety of alkali metal and alkaline earth salts. In addition, the effect of high pressure on the electrical conductivity in some of those materials has been presented.<sup>12</sup> In PEO to date, it appears that only the  $\gamma$  relaxation has been studied at high pressures.<sup>13</sup> In the present paper, the effect of pressure on the glass transition relaxation,  $\alpha_a$ , is reported. In addition, the previously reported data for the effect of pressure on the  $\gamma$  relaxation<sup>13</sup> are reanalyzed in terms of a reduced plot. Finally, in order to gain further information concerning  $\gamma$  and  $\alpha_a$ , different molecular weights have been studied.

## II. EXPERIMENT

The PEO was obtained from Polysciences, with MW  $1.85 \times 10^4$  to  $5 \times 10^6$ . All but the  $1.85 \times 10^4$  samples were melt-pressed at about  $100^\circ\text{C}$  using a Buehler Simplimet II press. The melt-pressed samples were about 25 mm in



diameter and 1.5 mm thick. Aluminum electrodes were evaporated onto the surfaces in a three terminal configuration. For the vacuum measurements, the guarded electrode was about 14 mm in diameter while for the high pressure measurements (MW  $5 \times 10^6$ ) it was 9 mm in diameter. The remainder of the guarded side of the sample was the guard ring and the full face of the opposite side of the sample was evaporated as the high electrode. The guard gap was on the order of 0.1 mm wide.

Measurements of the capacitance and conductance divided by the angular frequency were performed in vacuum over the temperature range 5.5-320K as described elsewhere.<sup>9</sup> In the present case, a new bridge constructed by one of the authors (C.G.A.) was used to perform the measurements. The new, fully automated bridge operates at seventeen frequencies over the range  $10$ - $10^5$  Hz.

The data were transformed to the complex dielectric constant,  $\epsilon^* = \epsilon' - j\epsilon''$  using procedures described in detail elsewhere.<sup>9</sup> Once again no thermal expansion correction was included in the data reduction. The results of room temperature geometrical measurements and the capacitance data at 5.5K yielded  $\epsilon' = 2.87, 3.01, 2.89$ , and  $2.95$  for MW  $4 \times 10^6, 6 \times 10^5, 3 \times 10^5$ , and  $1 \times 10^5$  respectively. These values agree to within the experimental uncertainty in that the precision is estimated to be about 3%. The values are, however, not accurate to 3% as thermal expansion of the samples was neglected in the data analysis.

The MW  $1.85 \times 10^4$  samples were not melt-pressed as they were received as platelets. They were also evaporated in a three terminal configuration with a 9 mm diameter guarded electrode. The thickness was about 0.5 mm and the guard ring was about 5 mm wide. However, a geometrical measurement was

not used. The low temperature value of  $\epsilon'$  was set equal to the average of the values quoted above for the higher molecular weight materials.

The high pressure measurements were carried out in the vessel described elsewhere.<sup>14</sup> The pressure fluid was a mixture of pentane and Spinesstic 22 and the temperatures were achieved using a mechanically refrigerated ethylene glycol bath. The vacuum audio frequency complex impedance measurements were performed using a different, fully automated bridge constructed by one of the authors (C.G.A.) which operates with a more restricted frequency range.

#### IV. RESULTS AND DISCUSSION

Figure 1 shows typical vacuum electrical relaxation spectra at five frequencies between  $10^2$  and  $10^5$  Hz for PEO, in this case for a sample of molecular weight  $4 \times 10^6$ . Figure 2 shows the data at  $10^3$  Hz for five molecular weights between  $1.85 \times 10^4$  and  $4 \times 10^6$ . The relaxation spectra at five frequencies for the  $1.85 \times 10^4$  molecular weight material are shown in Figure 3. Two strong features are observed, the  $\gamma$  relaxation with peaks from about 140-200K and the  $\alpha_a$  relaxation. It is interesting to note that at the highest frequency, the  $\alpha_a$  and  $\gamma$  relaxations merge as predicted by Porter and Boyd.<sup>6</sup> In addition, there is a weak relaxation region in all of the samples from 60-100K. The latter relaxation will not be discussed further in this paper. As no features were observed below 50 K, that region is not shown in the plots.

The first result of interest is that it is clear from Fig 2 that the  $\gamma$  relaxation does not vary much with molecular weight. If anything, there

is a slight decrease in the strength as the molecular weight decreases. This argues against assigning it to chain end hydroxyl groups.<sup>5</sup> A similar result and conclusion was obtained by Se et al.<sup>7</sup>

In order to gain further information concerning the  $\gamma$  relaxation, high pressure measurements were performed and have been reported previously.<sup>13</sup> In that paper, the data were analyzed using the "standard" technique of fitting a Cole-Cole expression to individual data sets. The relaxation time for each pressure and temperature was then determined from the peak position. In the present paper the data are reanalyzed in terms of a "reduced plot." The plot is shown in Fig. 4. All of the data for 17 frequencies, 3 temperatures, and 7 pressures have been "normalized" to a common curve using least square fitting computer techniques described elsewhere.<sup>13</sup> In Ref. 13, this type of fitting procedure was applied to vacuum data using a Havriliak-Negami expression. In the present case, the empirical expression of Jonscher<sup>15</sup> has been used:

$$\epsilon'' = \frac{\epsilon_s - \epsilon_\infty}{[(\omega/\omega_p)^{-m} + (\omega/\omega_p)^{(1-n)}]} \quad (1)$$

The significant best fit parameters are  $n=0.84$  and  $m=0.33$ . The strength and peak position are arbitrary, however, further information can be gained from the amount of shift in  $\log_{10}(\omega_p)$  necessary to reach the master curve. The results for these logarithmic frequency shifts of the data to the master curve for both pressure and temperature are shown in Fig. 5. The resultant slopes for the pressure data are given in Table I. These were then used to calculate the activation volume via:

$$\Delta V^* = - kT \frac{d \ln w_p}{dP} \quad (2)$$

The resultant activation volumes are also listed in Table I along with the results from the previous paper. The agreement is quite good considering the widely differing techniques used to arrive at the results. The activation volume, 3-4 cm<sup>3</sup>/mol, is very small which supports assigning the relaxation to either chain end hydroxyl groups or very small segments of the polymer chain. However, considering the above results of the molecular weight studies, the latter mechanism is to be preferred.

Finally, the variation of the glass transition with molecular weight is of interest. Since the strength of  $\alpha_a$  decreases with decreasing molecular weight, it is apparent that the degree of crystallinity increases with decreasing molecular weight over the range of molecular weights used in the present study. This is a well known phenomenon in PEO. Also, the work of Faucher et al.<sup>16</sup> indicates that there is a maximum in the glass transition temperature at a molecular weight of about 6000. This increase in  $T_g$  with decreasing molecular weight is evident in Figure 2, although the shift in peak positions between the  $1 \times 10^5$  and the  $1.85 \times 10^4$  molecular weight samples is enhanced by the change in the frequency dependence of the peak position which can be observed by comparison of this effect in figures 1 and 3.

The results for the high molecular weight material are particularly interesting in that a peak for  $\alpha_a$  was never observed in frequency at any single temperature over the frequency range  $10$  to  $10^5$  Hz, although it is observed in the temperature sweeps. For the 18,500 MW material, however,

the material exhibited more normal behavior with the peak being observed in frequency as is apparent in Figure 3. However, as mentioned above, this is the only material which was not melt-pressed and thus the result may not solely be a consequence of the molecular weight. Experiments to determine the origin of this phenomenon are currently being undertaken.

As the effect of pressure on the glass transition in PEO does not appear to have been reported previously, those measurements were carried out for the high molecular weight material. Some of the data at 1000 Hz are shown in Fig. 6. For this peak, very strong shifts with pressure are observed as is expected for a glass transition. The shift of the peak position,  $T_{\alpha}$ , with pressure is shown for two frequencies in Fig. 7 together with the best fit of the following equation to the data:

$$T_{\alpha} = T_{\alpha}^0 + BP + CP^2 \quad (3)$$

The best fit parameters for the two frequencies and those for a lower correlation fit at a third frequency are listed in Table II. The curvature which is apparent in the plots is consistent with the predictions of the retical treatments involving coupling of relaxation phenomena<sup>17</sup> and with pressure results for other polymers.<sup>18</sup>

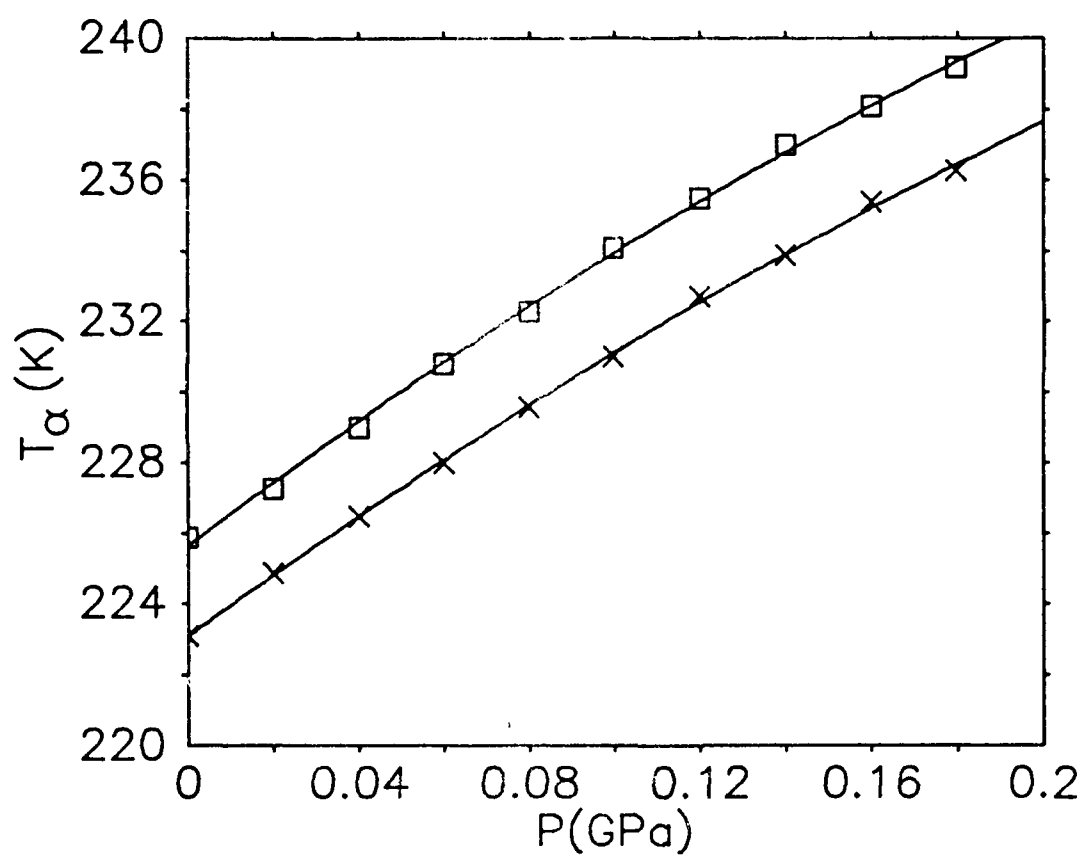
Since the peaks were not observed in frequency, a complete treatment in terms of the WLF equation cannot be carried out. However, both the frequency dependence of the effect of pressure on  $T_{\alpha}$  and the magnitude of  $dT_{\alpha}/dP$  agree qualitatively with the predictions of Arentas and Akrivis-Tubridi<sup>18</sup> who show that:

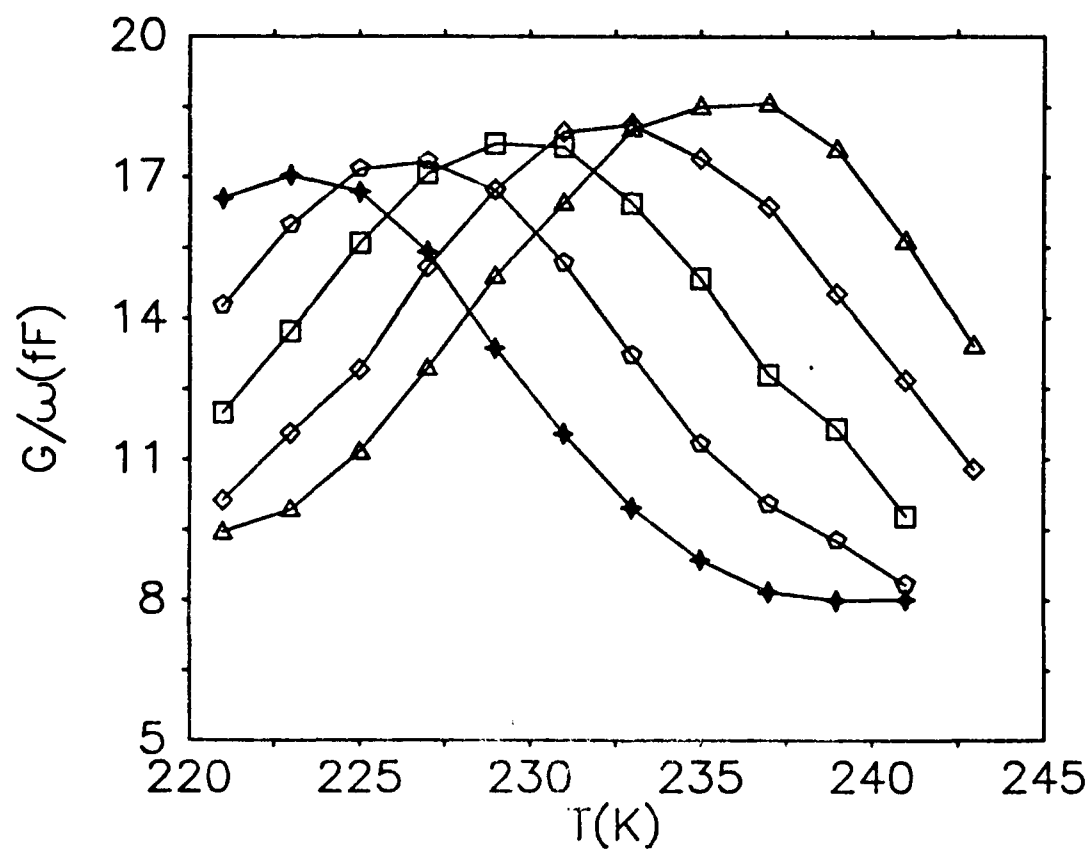
$$\frac{dT_{\alpha}}{dP} = \frac{\Delta V^*}{\Delta E^*} (T_{\alpha}^0 - T_r) \quad (4)$$

where  $T_{\alpha}^0$  represents the zero pressure peak position,  $\Delta E^*$  and  $\Delta V^*$  are the activation enthalpy and volume, respectively, and  $T_r$  is the minimum temperature at which the activated process is still possible. It is clear from the results that  $dT_{\alpha}/dP$  and  $T_{\alpha}^0$  are larger for larger frequencies. This proportional dependence on frequency for both quantities is consistent with Eq. (4). Further, the values of  $T_{\alpha}^0$  and  $dT_{\alpha}/dP$  for PEO would fit well on the plot in Fig. 5 of Quested and Oskooie-Tabrizi<sup>18</sup> and thus PEO can be grouped with poly vinyl acetate (PVAc), acrylonitrile-butadiene-styrene (ABS), polyurethane elastomers (PU) and polyvinylidene fluoride (PVDF), in that it follows Eq. (4).

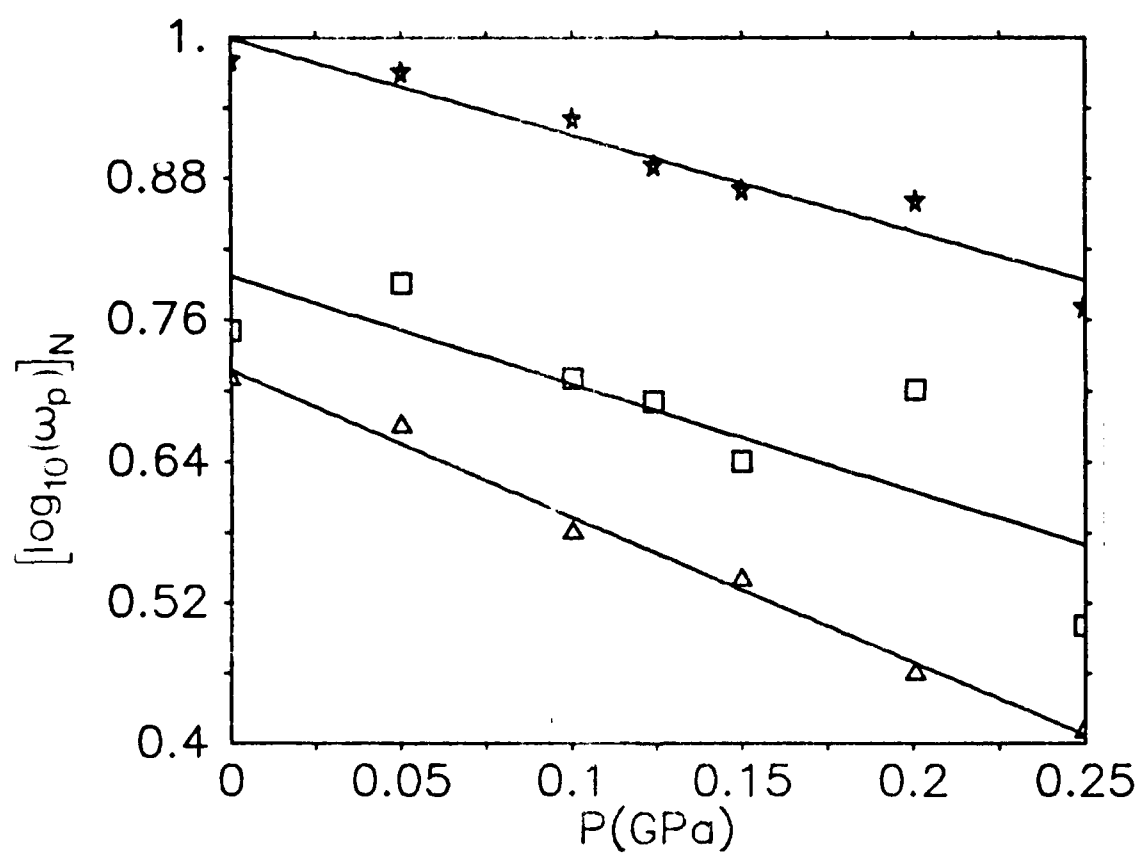
#### 7. SUMMARY

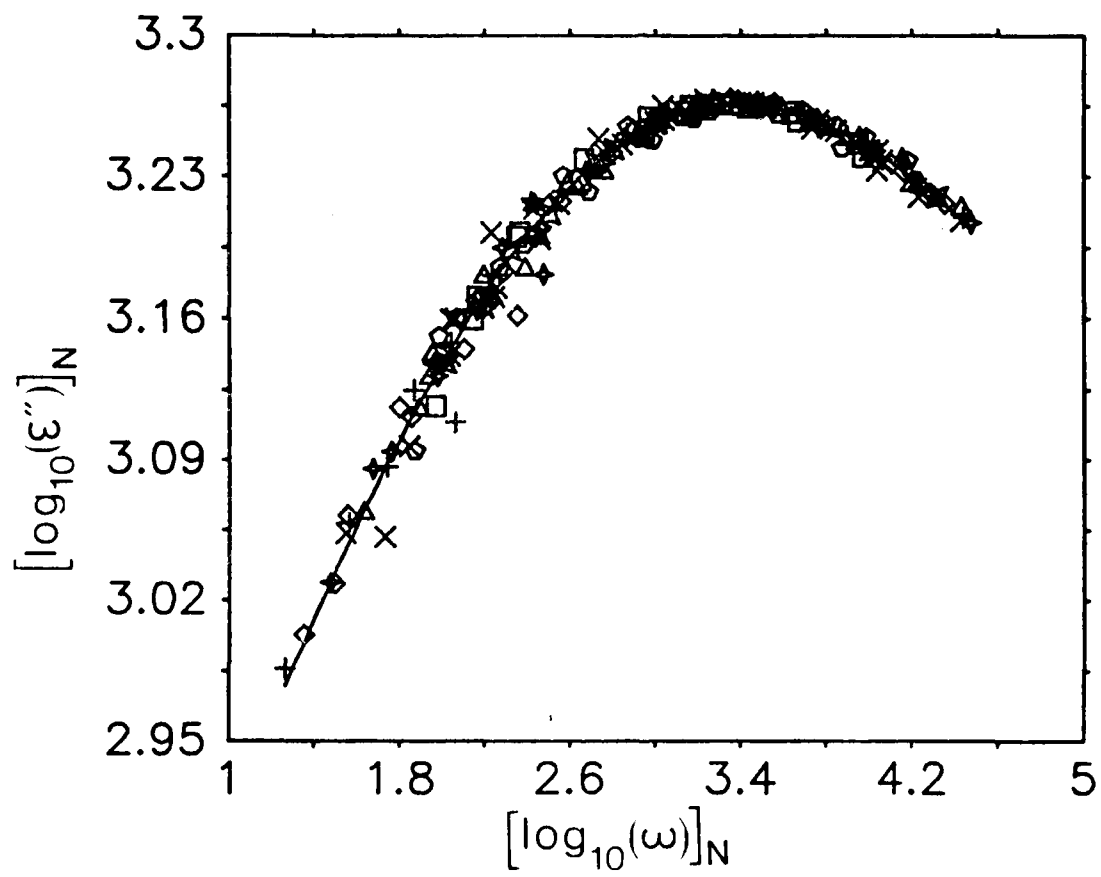
In summary, then, vacuum dielectric frequency complex admittance measurements have been carried out on PEO at low temperatures for a variety of molecular weights. The  $\beta$  relaxation varies very little over the range of molecular weights studied. This represents evidence against assigning the  $\beta$  relaxation to motion of end groups. Next, previously reported data for the  $\gamma$  relaxation are reanalyzed using a reduced plot. The activation volume obtained is in good agreement with the previous work and the fact that a very small value is found implies that the relaxation is associated with small segments of the polymer chain. It is found that the relaxation associated with the glass transition is only observed in temperature for

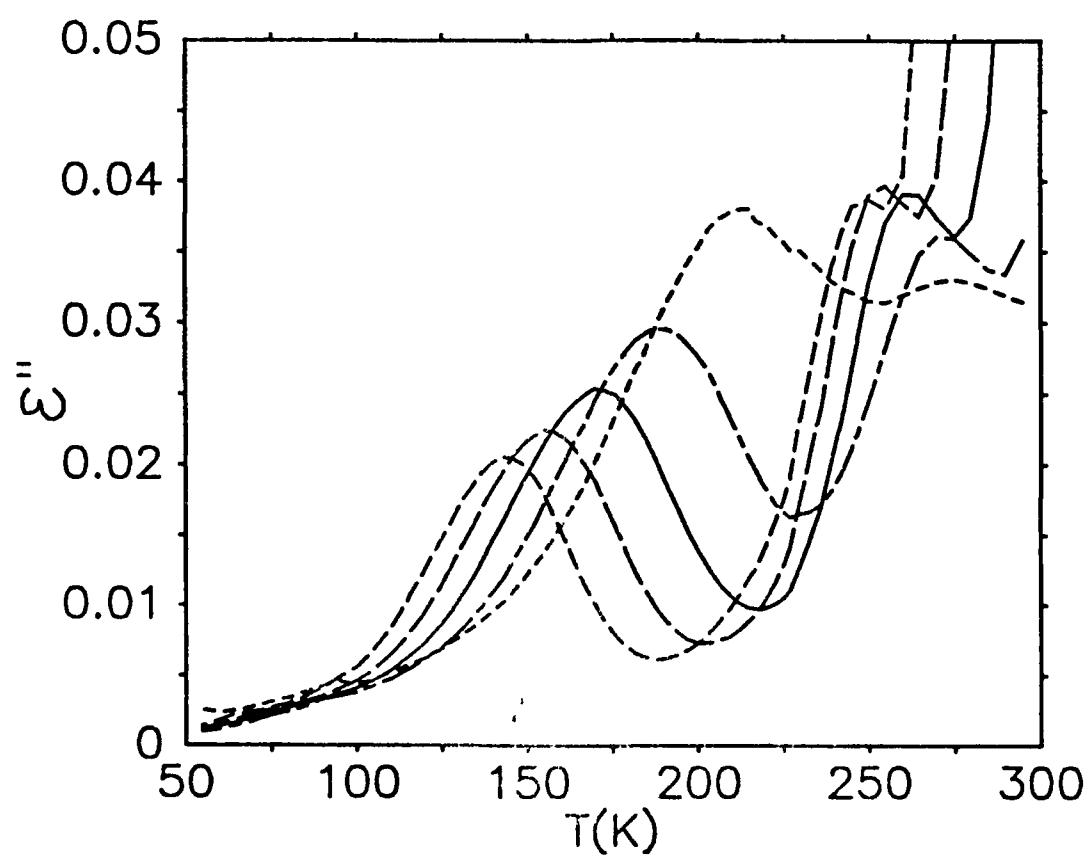


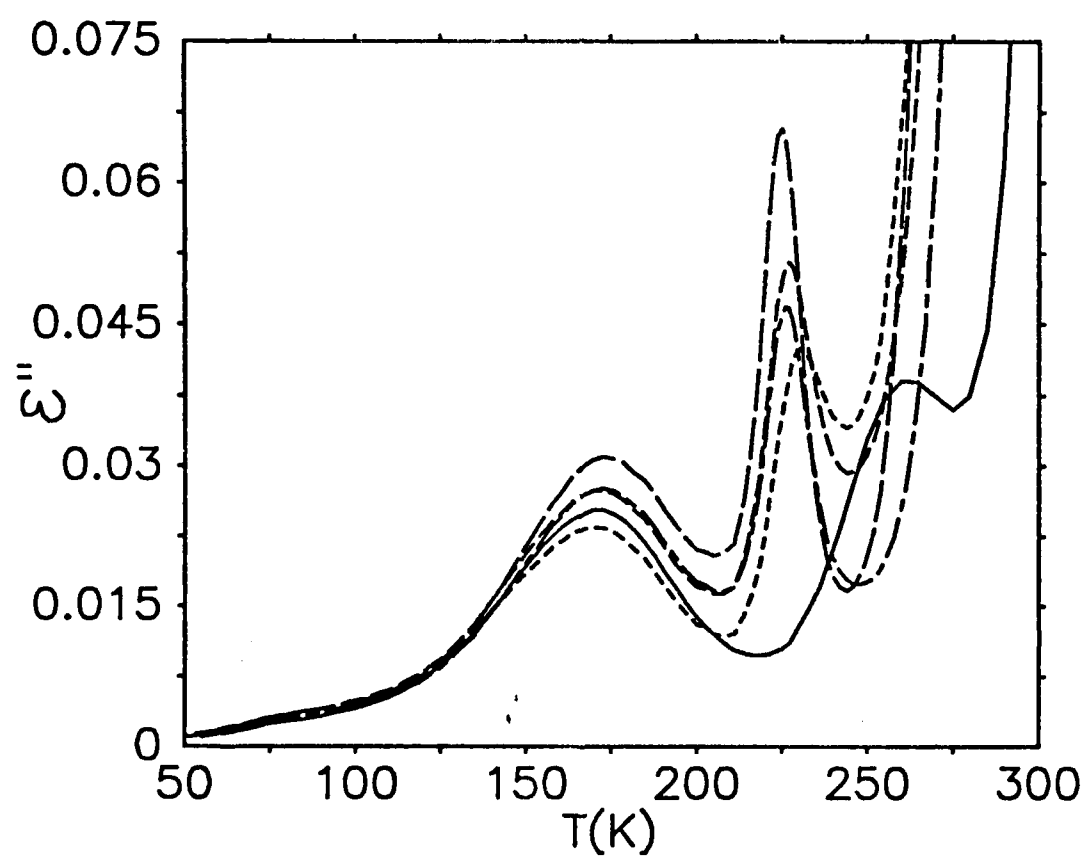


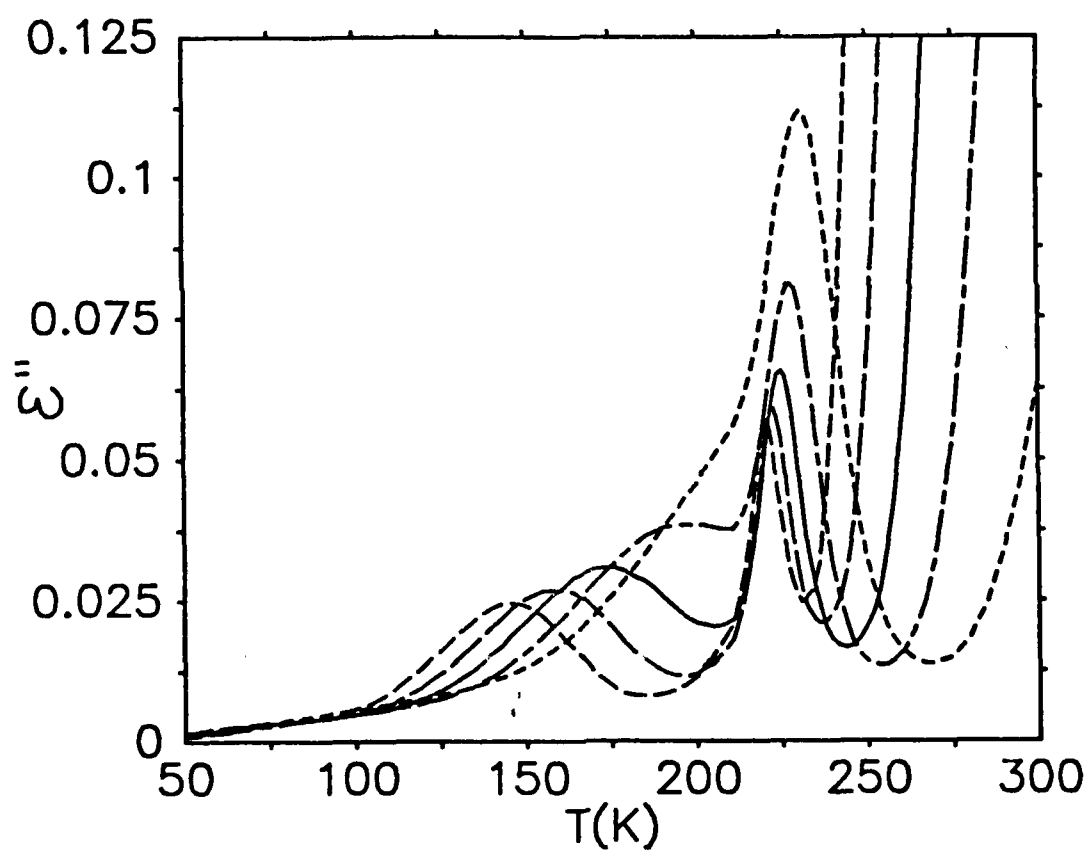












F<sub>0</sub>'

Figure 6.  $G/\omega$  (pF) vs.  $T(K)$  at several pressures at 1000 Hz in the region of the glass transition for PEO (MW  $5 \times 10^6$ ). The curves from left to right are 0.0001 (1 atm), 0.04, 0.08, 0.12, and 0.16 GPa. For clarity, straight line segments connect the datum points and data at other pressures have been omitted.

Figure 7. Peak position vs.  $P(\text{GPa})$  at two frequencies, 1000 Hz (crosses) and 10,000 Hz (squares), for the  $\alpha_a$  relaxation in PEO (MW  $5 \times 10^6$ ). Also shown are the best fit quadratic curves.

#### FIGURE CAPTIONS

Figure 1.  $\epsilon''$  vs.  $T(K)$  for PEO with molecular weight  $4 \times 10^6$ . The curves (from left to right) are: medium dash- $10$  Hz; long dash- $10^2$  Hz; solid- $10^3$  Hz; chain link- $10^4$  Hz; short dash- $10^5$  Hz. Straight line segments connect the datum points which are not shown.

Figure 2.  $\epsilon''$  vs.  $T(K)$  for PEO at  $1000$  Hz with various molecular weights: long dash- $4 \times 10^6$ ; medium dash- $6 \times 10^5$ ; chain link- $3 \times 10^5$ ; short dash- $1 \times 10^5$ ; solid- $1.85 \times 10^4$ . Straight line segments connect the datum points which are not shown.

Figure 3.  $\epsilon''$  vs.  $T(K)$  for PEO with molecular weight  $1.85 \times 10^4$ . The curves (from left to right) are medium dash- $10$  Hz; long dash- $10^2$  Hz; solid- $10^3$  Hz; chain link- $10^4$  Hz; short dash- $10^5$  Hz. Straight line segments connect the datum points which are not shown.

Figure 4. "Reduced plot" for the  $\gamma$  relaxation in PEO (MW  $5 \times 10^6$ ). The best fit Jonscher curve and data points for 17 frequencies, 3 temperatures, and 7 pressures are shown. The peak position and strength are arbitrary.

Figure 5. Peak shift vs. pressure at three temperatures, 185, 182, and 179K from top to bottom, for the results shown in Figure 4. Also shown are the best fit straight lines.

Table II

Best fit parameters in Eq. 3 for peak position vs. pressure for the  $\alpha_a$  relaxation in pure PEO.

$f(\text{Hz})$	$T_{\alpha}^0$	$B(\text{GPa}^{-1})$	$C(\text{GPa}^{-2})$	RMS Deviation
$10^3$	223.1	87.8	-75.3	0.11
$10^{3.5}$	224.3	87.9	-56.4	0.21
$10^4$	225.6	91.8	-86.7	0.15



Table I

Pressure derivative of the relaxation time and activation volume  
for the gamma relaxation at various temperatures for pure PEO.

T(K)	$\frac{d \ln \omega}{dP}$ (GPa) <sup>-1</sup>	$\Delta V^*$ (cm <sup>3</sup> /mol)	$\Delta V^*$ (cm <sup>3</sup> /mol) <sup>a</sup>
<u>Sample #2</u> (Cast film)			
179	2.9	4.3	4.3
182	2.1	3.2	-
185	1.9	2.9	4.7

a. Reference 13.

14. J. Fontanella, C. Andeen, and D. Schuele, Phys. Rev., B6, 582 (1972).
15. A. K. Jonscher, Colloid and Polymer Sci., 253, 231 (1975).
16. J. A. Faucher, J. V. Koleske, F. R. Santee, Jr., J. J. Stratta, and C. W. Wilson, III, J. Appl. Phys., 37, 3962 (1966).
17. I. Havlicek, M. Ilavsky, and J. Hrouz, J. Macromol. Sci.-Phys., B21, 425 (1982).
18. D. L. Questad and M. Oskooie-Tabrizi, J. Appl. Phys., 53, 6574 (1982).

## REFERENCES

1. D. E. Fenton, J. M. Parker, and P. V. Wright, *Polymer* 14, 589 (1973).
2. M. B. Armand, J. M. Chabagno and M. J. Duclot, in Fast Ion Transport in Solids, J. N. Mundy and G. K. Shenoy, Eds., Pergamon Press, New York, 1979, p. 131.
3. D. F. Shriver, B. L. Papke, M. A. Ratner, R. Dupon, T. Wong, and M. Brodwin, *Solid State Ionics* 5, 83 (1981).
4. N. G. McCrum, B. E. Read, and G. Williams, Anelastic and Dielectric Effects in Polymeric Solids, (John Wiley & Sons, New York, 1967).
5. P. Hedvig, Dielectric Spectroscopy of Polymers, (Adam Hilger Ltd., Bristol, 1977).
6. C. H. Porter and R. H. Boyd, *Macromolecules* 4, 589 (1971).
7. K. Se, K. Adachi, and T. Kotaka, *Polymer Journal* 11, 1009 (1981).
8. J. J. Fontanella, M. C. Wintersgill, J. P. Calame, and C. G. Andeen, *Solid State Ionics*, 8, 333 (1983).
9. M. C. Wintersgill, J. J. Fontanella, J. P. Calame, D. R. Figueroa, and C. G. Andeen, *Solid State Ionics*, 11, 151 (1983).
10. J. J. Fontanella, M. C. Wintersgill, J. P. Calame, and C. G. Andeen, *J. Polymer Sci.: Polymer Phys.*, 23, 113 (1985).
11. S. G. Greenbaum and J. J. Fontanella, in Relaxation in Complex Systems, eds. K. L. Ngai and G. B. Wright, (NTIS, Springfield, VA, 1984).
12. J. J. Fontanella, M. C. Wintersgill, J. P. Calame, F. P. Pursel, D. R. Figueroa, and C. G. Andeen, *Solid State Ionics*, 9&10, 1139 (1983).
13. J. J. Fontanella, M. C. Wintersgill, J. P. Calame, P. J. Welcher, and C. G. Andeen, *IEEE Trans. EI*, to be published.

some samples but is observed in both frequency and temperature for others. Finally, the relaxation associated with the glass transition was studied up to pressures of about 0.2 GPa for the high molecular weight material. The results are in qualitative agreement with recent theories.

#### ACKNOWLEDGMENTS

This work was supported in part by the Office of Naval Research.

DL/413/83/01  
GEN/413-2

TECHNICAL REPORT DISTRIBUTION LIST, GEN

	<u>No. Copies</u>		<u>No. Copies</u>
Office of Naval Research Attn: Code 413 800 N. Quincy Street Arlington, Virginia 22217	2	Dr. David Young Code 334 NORDA NSTL, Mississippi 39529	1
Dr. Bernard Doua Naval Weapons Support Center Code 5042 Crane, Indiana 47522	1	Naval Weapons Center Attn: Dr. A. B. Amster Chemistry Division China Lake, California 93555	1
Commander, Naval Air Systems Command Attn: Code 310C (H. Rosenwasser) Washington, D.C. 20360	1	Scientific Advisor Commandant of the Marine Corps Code RD-1 Washington, D.C. 20380	1
Naval Civil Engineering Laboratory Attn: Dr. R. W. Drisko Port Hueneme, California 93401	1	U.S. Army Research Office Attn: CRD-AA-IP P.O. Box 12211 Research Triangle Park, NC 27709	1
Defense Technical Information Center Building 5, Cameron Station Alexandria, Virginia 22314	12	Mr. John Boyle Materials Branch Naval Ship Engineering Center Philadelphia, Pennsylvania 19112	1
DTNSRDC Attn: Dr. G. Bosmajian Applied Chemistry Division Annapolis, Maryland 21401	1	Naval Ocean Systems Center Attn: Dr. S. Yamamoto Marine Sciences Division San Diego, California 91232	1
Dr. William Tolles Superintendent Chemistry Division, Code 6100 Naval Research Laboratory Washington, D.C. 20375	1		

ABSTRACTS DISTRIBUTION LIST, 359/627

Dr. Paul Delahay  
Department of Chemistry  
New York University  
New York, New York 10003

Dr. P. J. Hendra  
Department of Chemistry  
University of Southampton  
Southampton SO9 5NH  
United Kingdom

Dr. T. Katan  
Lockheed Missiles and  
Space Co., Inc.  
P.O. Box 504  
Sunnyvale, California 94088

Dr. D. N. Bennion  
Department of Chemical Engineering  
Brigham Young University  
Provo, Utah 84602

Mr. Joseph McCartney  
Code 7121  
Naval Ocean Systems Center  
San Diego, California 92152

Dr. J. J. Auborn  
Bell Laboratories  
Murray Hill, New Jersey 07974

Dr. Joseph Singer, Code 302-1  
NASA-Lewis  
21000 Brookpark Road  
Cleveland, Ohio 44135

Dr. P. P. Schmidt  
Department of Chemistry  
Oakland University  
Rochester, Michigan 48063

Dr. H. Richtol  
Chemistry Department  
Rensselaer Polytechnic Institute  
Troy, New York 12181

Dr. R. A. Marcus  
Department of Chemistry  
California Institute of Technology  
Pasadena, California 91125

Dr. E. Yeager  
Department of Chemistry  
Case Western Reserve University  
Cleveland, Ohio 44106

Dr. C. E. Mueller  
The Electrochemistry Branch  
Naval Surface Weapons Center  
White Oak Laboratory  
Silver Spring, Maryland 20910

Dr. Sam Perone  
Chemistry & Materials  
Science Department  
Lawrence Livermore National Laboratory  
Livermore, California 94550

Dr. Royce W. Murray  
Department of Chemistry  
University of North Carolina  
Chapel Hill, North Carolina 27514

Dr. B. Brummer  
EIC Incorporated  
111 Downey Street  
Norwood, Massachusetts 02062

Dr. Adam Heller  
Bell Laboratories  
Murray Hill, New Jersey 07974

Electrochimica Corporation  
Attn: Technical Library  
2480 Charleston Road  
Mountain View, California 94040

Library  
Duracell, Inc.  
Burlington, Massachusetts 01803

Dr. A. B. Ellis  
Chemistry Department  
University of Wisconsin  
Madison, Wisconsin 53706

Dr. Manfred Breiter  
Institut für Technische Elektrochemie  
Technischen Universität Wien  
9 Getreidemarkt, 1160 Wien  
AUSTRIA

ABSTRACTS DISTRIBUTION LIST, 359/627

Dr. David Aikens  
Chemistry Department  
Rensselaer Polytechnic Institute  
Troy, New York 12181

Dr. A. B. P. Lever  
Chemistry Department  
York University  
Downsview, Ontario M3J1P3

Dr. Stanislaw Szpak  
Naval Ocean Systems Center  
Code 6343, Bayside  
San Diego, California 95152

Dr. Gregory Farrington  
Department of Materials Science  
and Engineering  
University of Pennsylvania  
Philadelphia, Pennsylvania 19104

M. L. Robertson  
Manager, Electrochemical  
and Power Sources Division  
Naval Weapons Support Center  
Crane, Indiana 47522

Dr. T. Marks  
Department of Chemistry  
Northwestern University  
Evanston, Illinois 60201

Dr. Micha Tomkiewicz  
Department of Physics  
Brooklyn College  
Brooklyn, New York 11210

Dr. Lesser Blum  
Department of Physics  
University of Puerto Rico  
Rio Piedras, Puerto Rico 00931

Dr. Joseph Gordon, II  
IBM Corporation  
K33/281  
5600 Cottle Road  
San Jose, California 95193

Dr. Hector D. Abruna  
Department of Chemistry  
Cornell University  
Ithaca, New York 14853

Dr. D. H. Whitmore  
Department of Materials Science  
Northwestern University  
Evanston, Illinois 60201

Dr. Alan Bewick  
Department of Chemistry  
The University of Southampton  
Southampton, SO9 5NH ENGLAND

Dr. E. Anderson  
NAVSEA-56Z33 NC #4  
2541 Jefferson Davis Highway  
Arlington, Virginia 20362

Dr. Bruce Dunn  
Department of Engineering &  
Applied Science  
University of California  
Los Angeles, California 90024

Dr. Elton Cairns  
Energy & Environment Division  
Lawrence Berkeley Laboratory  
University of California  
Berkeley, California 94720

Dr. D. Cipris  
Allied Corporation  
P.O. Box 3000R  
Morristown, New Jersey 07960

Dr. M. Philpott  
IBM Corporation  
5600 Cottle Road  
San Jose, California 95193

Dr. Donald Sandstrom  
Boeing Aerospace Co.  
P.O. Box 3999  
Seattle, Washington 98124

Dr. Carl Kannewurf  
Department of Electrical Engineering  
and Computer Science  
Northwestern University  
Evanston, Illinois 60201

Dr. Richard Pollard  
Department of Chemical Engineering  
University of Houston  
4800 Calhoun Blvd.  
Houston, Texas 77004

ABSTRACTS DISTRIBUTION LIST, 359/627

Dr. M. Wrighton  
Chemistry Department  
Massachusetts Institute  
of Technology  
Cambridge, Massachusetts 02139

Dr. B. Stanley Pons  
Department of Chemistry  
University of Utah  
Salt Lake City, Utah 84112

Donald E. Mains  
Naval Weapons Support Center  
Electrochemical Power Sources Division  
Crane, Indiana 47522

S. Ruby  
DOE (STOR)  
M.S. 6B025 Forrestal Bldg.  
Washington, D.C. 20595

Dr. A. J. Bard  
Department of Chemistry  
University of Texas  
Austin, Texas 78712

Dr. Janet Osteryoung  
Department of Chemistry  
State University of New York  
Buffalo, New York 14214

Dr. Donald W. Ernst  
Naval Surface Weapons Center  
Code R-33  
White Oak Laboratory  
Silver Spring, Maryland 20910

Mr. James R. Moden  
Naval Underwater Systems Center  
Code 3632  
Newport, Rhode Island 02840

Dr. Bernard Spielvogel  
U.S. Army Research Office  
P.O. Box 12211  
Research Triangle Park, NC 27709

Dr. Aaron Fletcher  
Naval Weapons Center  
Code 3852  
China Lake, California 93555

Dr. M. M. Nicholson  
Electronics Research Center  
Rockwell International  
3370 Miraloma Avenue  
Anaheim, California

Dr. Michael J. Weaver  
Department of Chemistry  
Purdue University  
West Lafayette, Indiana 47907

Dr. R. David Rauh  
EIC Laboratories, Inc.  
111 Downey Street  
Norwood, Massachusetts 02062

Dr. Aaron Wold  
Department of Chemistry  
Brown University  
Providence, Rhode Island 02192

Dr. Martin Fleischmann  
Department of Chemistry  
University of Southampton  
Southampton SO9 5NH ENGLAND

Dr. R. A. Osteryoung  
Department of Chemistry  
State University of New York  
Buffalo, New York 14214

Dr. Denton Elliott  
Air Force Office of Scientific  
Research  
Bolling AFB  
Washington, D.C. 20332

Dr. R. Nowak  
Naval Research Laboratory  
Code 6170  
Washington, D.C. 20375

Dr. D. F. Shriver  
Department of Chemistry  
Northwestern University  
Evanston, Illinois 60201

Dr. Boris Cahan  
Department of Chemistry  
Case Western Reserve University  
Cleveland, Ohio 44106



ABSTRACTS DISTRIBUTION LIST, 359/627

Dr. Robert Somoano  
Jet Propulsion Laboratory  
California Institute of Technology  
Pasadena, California 91103

Dr. Johann A. Joebstl  
USA Mobility Equipment R&D Command  
DRDME-EC  
Fort Belvoir, Virginia 22060

Dr. Judith H. Ambrus  
NASA Headquarters  
M.S. RTS-6  
Washington, D.C. 20546

Dr. Albert R. Landgrebe  
U.S. Department of Energy  
M.S. 68025 Forrestal Building  
Washington, D.C. 20595

Dr. J. J. Brophy  
Department of Physics  
University of Utah  
Salt Lake City, Utah 84112

Dr. Charles Martin  
Department of Chemistry  
Texas A&M University  
College Station, Texas 77843

Dr. H. Tachikawa  
Department of Chemistry  
Jackson State University  
Jackson, Mississippi 39217

Dr. Theodore Beck  
Electrochemical Technology Corp.  
3935 Leary Way N.W.  
Seattle, Washington 98107

Dr. Farrell Lytle  
Boeing Engineering and  
Construction Engineers  
P.O. Box 3707  
Seattle, Washington 98124

Dr. Robert Gotscholl  
U.S. Department of Energy  
MS G-226  
Washington, D.C. 20545

Dr. Edward Fletcher  
Department of Mechanical Engineering  
University of Minnesota  
Minneapolis, Minnesota 55455

Dr. John Fontanella  
Department of Physics  
U.S. Naval Academy  
Annapolis, Maryland 21402

Dr. Martha Greenblatt  
Department of Chemistry  
Rutgers University  
New Brunswick, New Jersey 08903

Dr. John Wasson  
Syntheco, Inc.  
Rte 6 - Industrial Pike Road  
Gastonia, North Carolina 28052

Dr. Walter Roth  
Department of Physics  
State University of New York  
Albany, New York 12222

Dr. Anthony Sammells  
Eltron Research Inc.  
4260 Westbrook Drive, Suite 111  
Aurora, Illinois 60505

Dr. W. M. Risen  
Department of Chemistry  
Brown University  
Providence, Rhode Island 02192

Dr. C. A. Angell  
Department of Chemistry  
Purdue University  
West Lafayette, Indiana 47907

Dr. Thomas Davis  
Polymer Science and Standards  
Division  
National Bureau of Standards  
Washington, D.C. 20234

Ms. Wendy Parkhurst  
Naval Surface Weapons Center R-33  
Silver Spring, Maryland 20910

**END**

**FILMED**

**9-85**

**DTIC**